SPECIFICATION

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THERMOPLASTIC POLYMER EXTRUSION BENDING

Background of Invention

[0001] Thermoplastic polymer extrusions having one or more cavities or hollows (hereinafter "cavities") are widely used, particularly in construction industries. Examples include rigid thermoplastic pipe and plastic framing materials for windows. In the latter applications, the extrusions protect, replace, and/or fit closely with associated wooden or metal structures and/or lower maintenance or construction costs. Such extrusions are typically produced in straight preformed sections that can be bent as required for particular applications. But bending may cause kinking, cracking and/or distortion of the extrusions (particularly the cavities) that degrades their external appearance and/or their fit with other structures. Several methods of avoiding or minimizing such bending-related problems are known.

[0002] For example, methods and apparatus for bending rigid thermoplastic pipe are discussed in U.S. Patent Nos. 5,407,613 and 5,593,708 (Schulte), and U.S. Patent No. 5,765,285 (Buy, et al.), each patent incorporated herein by reference. Some of these methods include heating the pipe to a temperature at which it can be plastically deformed, having previously inserted a flexible "snake" or other internal support (such as a coil spring) to prevent cross-sectional narrowing of the pipe cavity or pipe opening during bending. Subsequent cooling of the extrusion and removal of the supporting insert results in retention by the extrusion of the desired curved shape. A similar technique has been practiced in bending vinyl extrusions for use in framing "arch top" or "round top" windows.

[0003]

But these methods of extrusion bending have inherent deficiencies. For example, there may be lot-to-lot variations in the inside dimensions of the extrusion cavities

that make it difficult to insert closely fitting snakes or other supports. Additionally, if a support insert is removed while an extrusion is still at a temperature where plastic deformation can occur, distortion of the extrusion may result. On the other hand, if a support insert is left in place too long during the cooling phase after bending, it may be difficult or impossible to remove without damage to the insert and/or the extrusion.

[0004] In the '285 patent referenced above, Buy, et al. propose to avoid problems in bending pipe by eliminating the use of removable inserts altogether. Instead, the '285 patent describes a close fitting metal sleeve or tube that is slipped over a pipe to form a composite structure that can then be bent in a commercial tubing bender without kinking or cracking at the bend. Unfortunately, this method is poorly suited for use with extrusions having relatively complex external shapes and cavities such as those commonly needed in window framing. Thus, a better method of bending these more complex extrusions is needed.

Summary of Invention

[0005] Generally longitudinal cavities may be formed in an extrusion to save on materials, to reduce weight and/or to mate with other structures. Depending on their shape and position in an extrusion, certain cavities may tend to become distorted if the extrusion is bent. The present invention relates to bending a preformed thermoplastic polymer extrusion that comprises at least one cavity without materially distorting the extrusion cavity. By maintaining the size and shape of cavities substantially constant during the bending process, methods of the present invention preserve important external appearances and/or functions of an extrusion in its new curved shape.

[0006] As noted in the Background, employing removable support inserts such as springs or snakes to preserve the shape of selected extrusion cavities during bending is problematic. Methods of the present invention avoid such problems by instead filling one or more cavities with polymer foam that is easily formed within each such cavity. A preferred embodiment of these methods is schematically illustrated in the accompanying drawing and discussed in greater detail below.

[0007]

As foam is formed in an extrusion cavity from a mixture of ingredients, the foam

expands to fill the available space, taking on the cavity's exact shape. Subsequent curing of the foam in the cavity creates a new and closely-conforming internal support structure for the cavity. With an appropriate choice of compressive strength and/or related parameters such as density, the cured foam can be made to resist distortion of the cavity during bending.

[0008] After curing of the foam, which is an exothermic process, the extrusion is heated as necessary to attain a first temperature (sometimes called the heat deflection or plastic deformation temperature). After reaching this temperature, the extrusion can be plastically deformed as it is bent on a curved mandrill without kinking or cracking. A smoothly curved bend is ensured because, notwithstanding the heating and bending of the extrusion, the cured foam resists cross-sectional narrowing or distortion of cavities in which it has been cured.

[0009] The smoothly curved bend is further preserved by leaving the curved extrusion on the mandrill while the extrusion is cooled to a second temperature that is below its plastic deformation temperature. The cooling sets the smoothly curved extrusion's new shape, which will not materially change if the extrusion is then removed from the mandrill for further cooling to room temperature.

Brief Description of Drawing

[0010] The drawing graphically illustrates steps in a preferred method of bending a representative thermoplastic vinyl polymer extrusion.

Detailed Description

[0011]

Referring to Step 10 on the drawing, the choice of ingredients for the foam-forming mixture is seen to be an early requirement in methods of the present invention. In preferred embodiments, a polyisocyanate based foam may be formed by pouring hand-mixed ingredients in each desired cavity. Alternatively, foam may be formed by injecting directly into the cavity (as from a mixing head) a mixture comprising an organic polyisocyanate, one or more active hydrogen-containing compounds, and one or more expansion agents (blowing agents). Descriptions of polymer foam formation and curing, including examples of the above ingredients and additional components of the mixture such as catalysts and surfactants, are provided

in U.S. Patent Nos. 4,943,597 and 4,972,003 (Grunbauer, et al.) and 5,164,419 (Bartlett, et al.), each patent incorporated herein by reference.

[0012] Whatever the mixture ingredients chosen may be, preparation of a foam that exhibits attractive physical properties is easier if the ingredients are readily miscible with one another. Further, high-efficiency mixing procedures are preferably employed to ensure an even distribution of all starting materials.

[0013] Since the polymerization reaction that initiates foam formation is exothermic, heat is available to vaporize small encapsulated pockets of one or more liquid blowing agents that may be present. These small amounts of vapor expand to form bubbles in the liquid phase of the polymerization reaction, and the bubbles become foam cells as polymerization progresses. Thus, a polymer foam is created that, in preferred embodiments, subsequently cures as polymerization is completed within the cavity (Step 12) to form a polyurethane foam.

[0014] Cured polymer foam may have a range of physical properties (e.g., density, cell size, compressive strength, friability, and flexibility), depending largely on the specific choices of ingredients for the above mixture. Because of the wide range of demands that may be placed on the foam in preventing distortion of extrusion cavities during bending, as well as the different conditions that may exist during foam curing, no single foam formulation will necessarily be satisfactory for all applications.

[0015] For example, the amount of heat produced during the polymerization reaction is important for at least two reasons. First, some of the heat may be used to vaporize liquid blowing agents. Second, depending on the size and number of extrusion cavities to be foam-filled, enough heat may be generated as the foam is formed and cured to raise portions of the polymer extrusion's temperature significantly above, for example, about 70 degrees Celsius. For preferred vinyl polymer extrusions, 70 degrees Celsius is near the heat deflection (or plastic deformation) temperature.

[0016] Thus, 70 degrees Celsius is indicated as representative of the first temperature T_1 in Step 14. It is near the actual preferred bending temperature for a representative class of vinyl extrusions to which methods of the present invention may be applied.

[0017] The temperature at which these same vinyl compositions were originally extruded

(about 160 degrees Celsius) is only about 90 degrees Celsius above the heat deflection temperature. As a vinyl extrusion approaches its own extrusion temperature, the risk of catastrophic distortion increases significantly. Effective control of overall extrusion temperature rise during foam filling and curing is a function of extrusion geometry as well as the chosen polymerization reaction. Important effects of this temperature rise on shaping a polymeric extrusion are disclosed in U.S. Patent No. 6,319,456 (Gilbert, et al.), incorporated herein by reference.

[0018] Another factor affecting extrusion temperature prior to bending, of course, is any external heat that may be applied. For example, relatively close temperature control may be maintained by a "wet" process, e.g., immersing the extrusion in a temperature-controlled glycol bath. Temperature control may also be achieved if an extrusion is heated by a "dry" process, e.g., placing it in a stream of heated air or under an infrared (radiant) heater. These processes allow achievement of substantial temperature equilibrium throughout an extrusion to obtain predictable and controlled plastic deformation during bending.

[0019] However, in some cases it may be desirable to allow temperature gradients to exist in an extrusion during bending on a curved mandrill (Step 18). If portions of an extrusion that experience the greatest stress during bending are also in a relatively more plastic state, these portions may beneficially experience the greatest stress relief. Simultaneously, other (less plastic) portions can serve to stabilize the overall structure during bending. See the '456 patent referenced above for an example of this technique.

[0020] The stress relief resulting from selective stretching of portions of a polymer extrusion during bending may also improve the local molecular structure of the polymer, conferring additional strength and hardness under certain conditions. See U.S. Patent No. 5,597,185 (Bray, et al.), for example. In this manner, the additional localized heating around cavities generated by the polymerization reaction may be used to advantage in certain embodiments.

[0021] Temperatures throughout an extrusion, including any foam-filled cavities, must be monitored or accurately estimated (Step 22) during cooling (Step 20) to ensure

there will be no undesired distortion after the extrusion is removed from the mandrill. Yet to shorten production delays, extrusions will preferably be removed from the mandrill (Step 24) soon after critical portions are safely below the heat deflection temperature (i.e., at a temperature T_2 below about 60 degrees Celsius for preferred formulations of vinyl extrusions).

[0022] Providing relatively greater stress relief to the more highly stressed portions of an extrusion undergoing bending may reduce the requirements for cavity stabilization that are placed on the foam. Foam usable in methods of the present invention preferably ranges in density from about 16 kg per cubic meter to about 320 kg per cubic meter. Foam density is an important determinant of the amount of stabilization the foam can provide to extrusion cavities, but foam cell size, the ratio of open to closed cells, and the resilience (or friability) of the foam may also be important. All of these parameters can be influenced by the choice of ingredients in the foam-forming mixture.

[0023] Example foam preparations are described in U.S. Patent No. 4,218,543 (Weber, et al.), incorporated herein by reference.